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Improved DFT – Based Channel Estimation Techniques for OFDM Signal

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) modulation is one of the most promising techniques used in wireless transmission systems. Performance of OFDM system in practice depends on channel estimation. Pilot tones are usually inserted within OFDM symbol for channel estimation. One of the most important methods for channel estimation is 'DFT-based channel estimation'. So it is considered in the present work. And two 'improved DFT-based channel estimation methods' are proposed and tested when operating over channels having different fading environments. The results of simulation tests show that better performance is achieved when compared to the system that uses conventional DFT-based channel estimation method. The proposed systems can work even without any prior knowledge about channel parameters.

Keywords : OFDM, channel estimation, DFT, fading channel.

I. INTRODUCTION

High data rate transmission over wireless channels is required by wireless systems for many applications. However, the increase in data rate and the presence of the fading effects of the wireless channels will cause more Inter Symbol Interference (ISI). For this reason, Orthogonal Frequency Division Multiplexing (OFDM) system is proposed, which showed more resistance against multipath fading effects [I, II]. Channel estimation is a critical part of OFDM receiver and its performance affects the whole OFDM system performance. Most common channel estimation techniques for OFDM signal over wireless fading channels rely on pilot insertion. The estimation methods in general suffer from the complexity problem, where usually there is a tradeoff between complexity and performance. It is required to introduce a simple technique for channel estimation with acceptable performance for OFDM [III].

Discrete Fourier transform (DFT)-based channel estimation combined with pilots' insertion method is one of the most useful channel estimation techniques for OFDM signal. The technique relies on eliminating the noise effects using DFT, where fast Fourier Transform (FFT) is usually used thus providing reduced complexity compared to other methods [IV]. An efficient iterative DFT-based channel estimation method with Multiple Input and Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system is proposed in [V]. An iterative process is used to select only the significant channel impulse response (CIR) components. Better performance is achieved using the proposed method compared to conventional DFT-based channel estimator.

A new DFT-based channel estimation method is presented for OFDM system in [VI]. By using transform domain cluster and discriminant analysis, the suggested algorithm adaptively removed the noise in the CIR. By removing the noise, the accuracy of channel estimation is improved. Conventional DFT-based channel estimation method was tested to enhance the performance of LS and MMSE and reduce Inter Carrier Interference (ICI) in [VII]. The results show that, DFT process for channel estimation achieved better performance by reducing the noise effect as well.
While many works tried to perform and enhance the DFT-based channel estimation method, the present work investigates two methods to improve DFT-based channel estimator with low implementation complexity. These are to be tested with different channel environments.

II. SYSTEM MODEL

The OFDM system is modelled and simulated using Matlab simulation program with steps representing the actual OFDM system processing. The system model is shown in Figure-1 in the form of flow chart. The first step is the initialization where the general parameters used are defined, such as; number of OFDM symbols, number of subcarriers, number of cyclic prefix (CP) samples, number of pilots, Signal to Noise power Ratio (SNR) range, and the channel type and parameters. The transmission is then started by generating random data bits followed by Quadrature Phase Shift Keying (QPSK) modulation after being converted to parallel transmission. A comb type pilot insertion is then used according to given number of pilots with almost equal spacing between them. Inverse Fast Fourier Transform (IFFT) is then applied as OFDM modulation to all subcarriers including the pilots. Cyclic prefix (CP) samples are added to the resulting symbol. The resulting OFDM symbols are transmitted through multipath fading channel using any of the channel models shown in Table-1. Additive White Gaussian Noise (AWGN) samples with zero mean are then added to the transmitted OFDM. A range of transmission bit rates are considered by varying the sampling interval (or it's reciprocal; the sampling rate) of the transmitted signal. Three different sampling intervals is considered for each channel these are; 10^{-4}, 10^{-5}, 10^{-6} sec.

At the receiver, the CP samples added at transmission are removed first, and then OFDM demodulation is performed using FFT process to retrieve the modulated signal. The Pilots are then

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extracted and channel estimation is implemented using Least Square (LS) method followed by Cubic-Spline interpolation to estimate channel components at non-pilot locations. The DFT-based channel estimation is then implemented using one of the proposed methods. Frequency domain equalization is then performed based on estimated channel components. QPSK demodulation/detection is finally used to extract the transmitted binary data bits. The transmission error is then calculated by comparing the detected data bits to the corresponding transmitted ones. The processes just mentioned are repeated for each SNR value within the pre-specified SNR rang. Details of the simulations and remarks on the main assumptions not clarified here can be found elsewhere [viii].

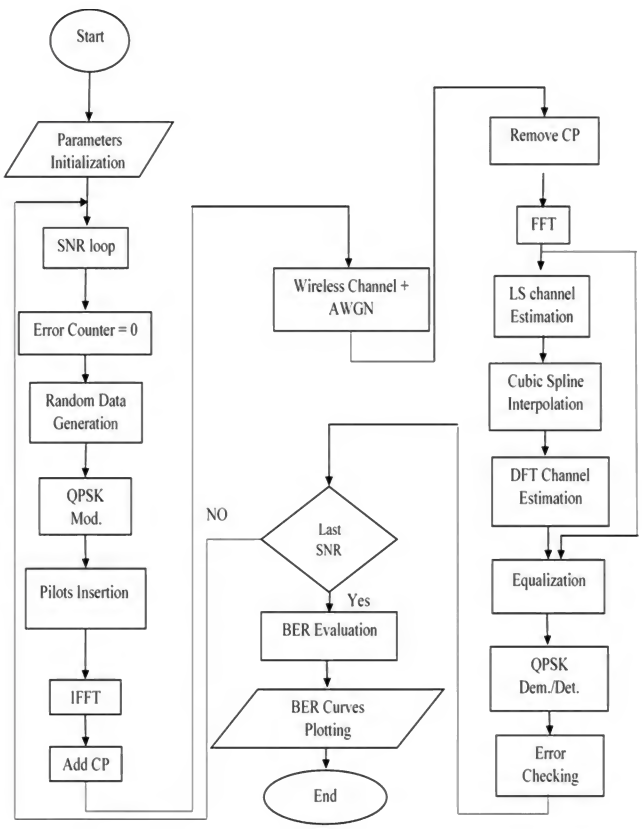

Figure-1 Flow chart of simulated OFDM system model.

Three types of International Telecommunication Union (ITU) channel models used in this work in order to test different channel environments. These are called here Indoor, Pedestrian, and Outdoor for simplicity[VIII]. Table-1 shows the channel parameters for each model [IX].

III CHANNEL ESTIMATION METHODS

Least Square (LS) estimation is the most common method with relatively low complexity. The LS is used here for the sake of comparison with the DFT-based techniques. Cubic spline interpolation is then used to evaluate other channel coefficients at non-pilot subcarriers locations.

Table-1 Channel Parameters for ITU models used [IX]

Taps No.	Indoor Office (A)		Pedestrian (B)		Outdoor (A)	
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)
1	0	0	0	0	0	0
2	50	-3	200	-0.9	310	-1.5
3	110	-10	800	-4.9	710	-9.0
4	170	-18	1200	-8.0	1090	-10.0
5	290	-26	2300	-7.8	1730	-15.0
6	310	-32	3700	-23.9	2510	-20.0

A. *Conventional DFT Method*

As shown in Figure-2, the first step in implementing DFT estimation is to apply IDFT for transforming the channel coefficients derived from LS and cubic spline into time domain. In the time domain, the number of CP samples (N_{cp}) is used as the preserved number of estimated channel components and ignoring all other channel components outside CP length. The reason here is the CP length is already chosen to cover the maximum channel delay, so all other components are considered to be the noise components. The latter are usually non-significant channel components and are ignored by setting their values to zero. These components correspond to noise caused by the channel. The time domain components are then transformed back to frequency domain using DFT for all channel components. The transformation back to frequency domain is done by using FFT with N points (the number of subcarriers) to compute channel components which are used in the equalization [VIII].

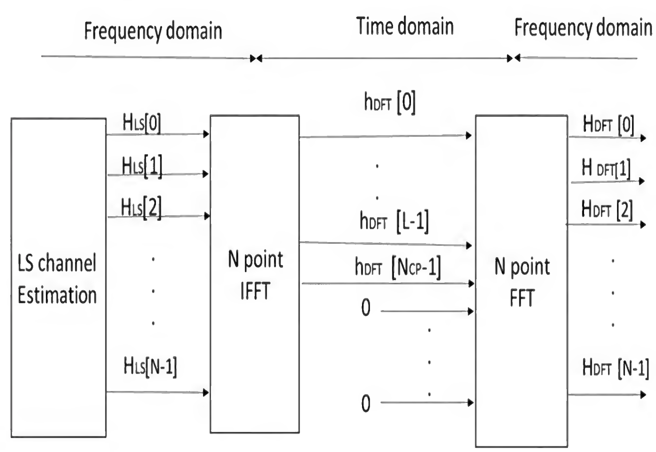

Figure-2 Block diagram of conventional DFT estimation.

B. *Method#1*

Using the number of CP samples in the conventional DFT method to distinguish the significant components of channel ensures that maximum channel delay is included in the estimation. The resulting components may contain noise

components within CP length. Thus, in order to separate signal and noise components, the most significant channel components are only reserved while the other non-significant components are ignored. This is performed by repeating DFT processing with lengths from 2 to N. In each processing trial, different numbers for the most significant channel components are considered. The performance for each case is then evaluated. The number that gives the best performance is then considered for each channel model and each sampling interval.

C. *Method#2*

In order to improve the operation of Method#1 and to allow some flexibility in its operation, Method#2 is proposed. The method here is aiming to select the best number of required components without any prior information about the channel such as the maximum channel delay. This Method can be considered as a direct modification of the original system proposed in [V]. In Method#2, the LS estimated channel components (H_{LS}) are converted into time domain using IFFT in order to compute h_{DFT}:

$$h_{DFT} = IFFT\ (H_{LS}) \qquad (1)$$

The maximum energy E_{max} outside the CP is calculated by:

$$E_{max} = MAX\ (|h_{DFTi}|^2) \qquad \text{for } i = (N_{CP}+1) \text{ to } N \qquad (2)$$

The energy of each channel component E_j inside CP length is computed as:

$$E_j = |\ h_{DFTj}\ |^2 \quad \text{for } j=1: N_{CP} \qquad (3)$$

E_{max} is compared to each calculated E_j, starting from the N_{cp}^{th} component to the first component

$$\text{If } E_n > E_{max} \quad \text{for } n=N_{CP}: 1 \qquad (4)$$

then the selected optimum number is taken to be n.

The selected optimal number (n) is then used as threshold number in DFT process as:

$$h_{DFT} = \begin{cases} h_{DFTi} & \text{for } i = 1:n \\ 0 & \text{Otherwise} \end{cases} \qquad (5)$$

FFT function is finally used to compute H_{DFT} components.

III. SIMULATION RESULTS

The results of the simulation tests are given in the form of plots of the obtained Bit Error Rate (BER) against the Signal to Noise power Ratio (SNR). The SNR here is determined by the corresponding E_b/N_o ratio in dB, where E_b is the average QPSK signal energy per data bit and N_o is the one sided power spectral density of the AWGN noise added in the channel. It can be shown that N_o can be represented by the corresponding AWGN noise variance [X]. The OFDM system parameters, the sampling rates (Ts) and the Doppler shifts (F_D) used in the simulation are as described in Table-2.

Indoor channel considered as fixed system, so its F_D value is set to zero, two different values of velocity are considered; 5 km/Hr with pedestrian channel and 15 km/Hr with outdoor channel. So the corresponding maximum Doppler shift F_D is approximately equal to 11 Hz for pedestrian channel and 33 Hz for outdoor channel.

Table-2 System Parameters

Parameters	Value	unit
Total Number of transmitted data bits	128000	Bit
Modulation	QPSK	---
Sampling Time (Ts)	10^{-4} , 10^{-5} , 10^{-6}	sec
Number of Subcarriers	64	---
Number of pilots	8 , 16	---
Cyclic prefix length (N_{cp})	16	---
Carrier Frequency (f_c)	2.4	GHz
Maximum Doppler shift (F_D)	0,11,33	Hz

The simulation results are represented for conventional channel estimation method (LS and Conventional DFT-based channel estimation) and the two proposed methods (Method#1 and Method#2). Figure-3 shows the results for the indoor channel, where 8-pilots are used with Ts of 10^{-4}, 10^{-5} sec., while 16-pilots are used with Ts of 10^{-6}sec. Figure-4 shows the results for pedestrian channel with F_D = 11 Hz using 8-pilots for Ts of 10^{-4} sec., while 16-pilots are used for Ts of 10^{-5}, and 10^{-6} sec. cases. Figure-5 shows the results for outdoor channel with F_D = 33 Hz with 8-pilots for Ts of 10^{-4} sec., while 16-pilots are used with Ts of 10^{-5}, and 10^{-6} sec.

For Method#1, Table-3 shows the preserved channel components by the estimator. For each channel and the corresponding Doppler shift and sampling interval, extensive simulation tests were carried out to find the required number of channel components. The latter represents are the most significant channel components that must be saved in DFT estimator according to channel condition.

As a final assessment of the results for all methods, the followings are worth to be mentioned; conventional DFT is characterized by its simplicity because it uses the number of CP samples as its number of significant channel components that must be saved in the DFT processing. The method can work without any prior information about the channel. Unfortunately, this method produced the worst performance.

Method#1 shows better performance than conventional DFT because it depends on testing each channel before deciding on the selected number of significant channel components. On the other hand, this procedure is rather a complicated approach due to the required time and processing to decide on the best components selection. This method is not preferred in practice since the channel may vary rapidly.

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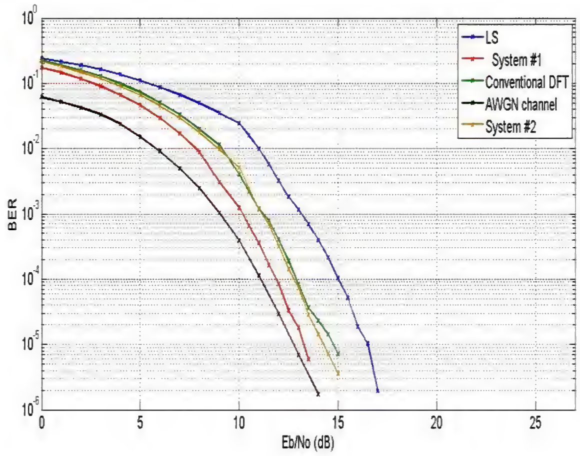
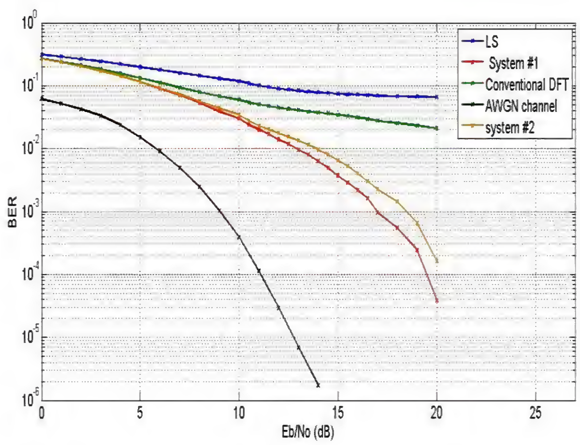
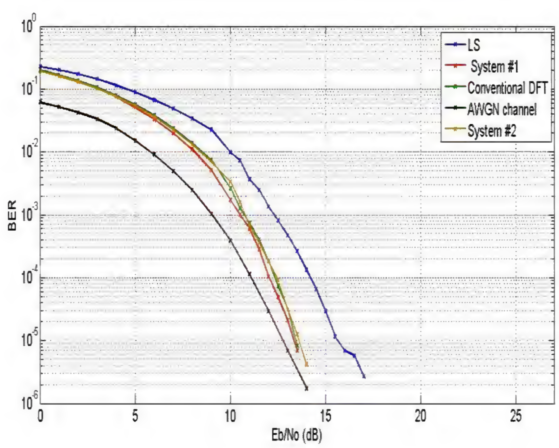


a- Ts = 10^{-4} sec

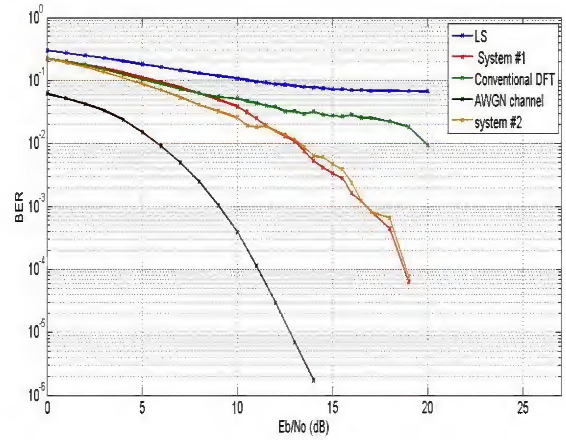


b- Ts = 10^{-5} sec

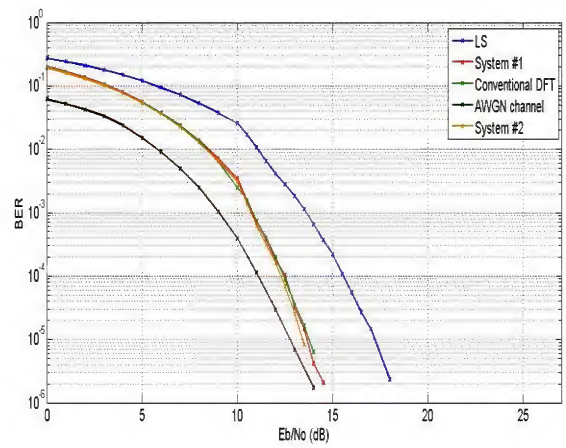


c- Ts = 10^{-6} sec

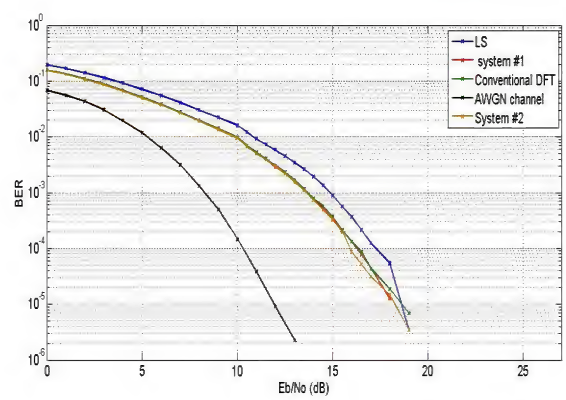
Figure-3 Simulation results for indoor channel



a- Ts = 10^{-4} sec



b- Ts= 10^{-5} sec



c- Ts= 10^{-6} sec

Figure-4 Simulation results for pedestrian channel

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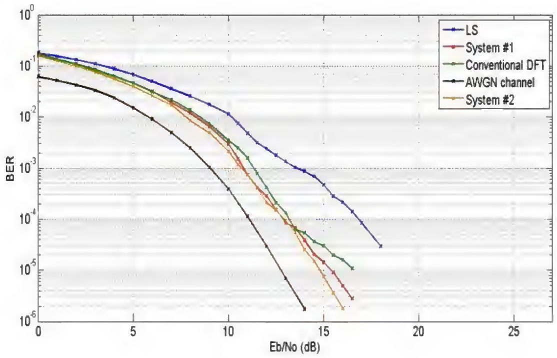
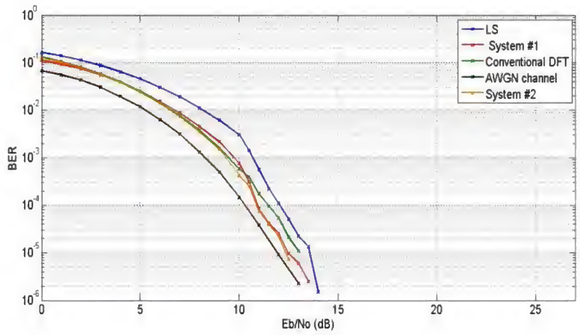
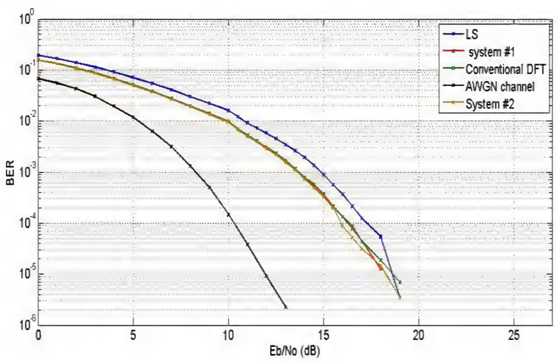


a- Ts = 10^{-4} sec



b- Ts= 10^{-5} sec



c- Ts= 10-6 sec

Figure-5 Simulation results for outdoor channel

Table-3 Optimum number of channel components selection for Method#1

Channel Type	Number of Pilots	Ts=10^{-4}	Ts=10^{-5}	Ts=10^{-6}
Indoor F_D = 0 Hz	8	1	5	Not Working
	16	Not Needed	Not Needed	8
Pedestrian F_D = 11Hz	8	5	Not Working	Not Working
	16	Not Needed	11	11
Outdoor F_D = 33 Hz	8	8	Not Working	Not Working
	16	Not Needed	9	11

Method#2 shows the same performance as that Method#1 in most cases while its implementation complexity is relatively low. It relies on prior checking to find the best choice of significant channel components without the need for channel information or any testing process.

IV. Conclusion

Two proposed methods to improve DFT based channel estimation for OFDM system over fading channel is presented. The methods achieved improvement in performance over conventional DFT estimator. Method#1 showed better performance and higher complexity when compared to conventional DFT due to its lengthy procedure for choosing the optimum number of significant channel components. Method#2 was able to achieve almost the same performance as that of Method#1 with much lower complexity and ability to work for channels without the need for any prior knowledge about its parameters.

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